

Mapping Emerging Interaction Technologies for Inclusive Co-Creation in Urban Planning

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Abstract

Urban planning today faces a dual challenge: the growing complexity of urban projects, involving more stakeholders at various stages of the projects, and a fragmented technological landscape where emerging digital tools remain largely experimental and prototypical, leaving planning systems without a comprehensive overview of how to integrate them. This mismatch creates communication gaps and limits the capacity of planning systems to respond effectively to emerging challenges. Digital technologies such as extended reality (XR), hybrid and tangible user interfaces are developed to support participatory processes in urban planning. However, due to their underdeveloped nature and the lack of a systematic overview, their integration into co-creation workflows remains uneven. This article shifts the focus from technological capabilities to the role of interaction technologies as mediators of spatial knowledge by developing an analytical framework that combines interaction qualities with knowledge governance dimensions. The framework is applied to map 36 interaction technologies. The results reveal fragmented capacities: Tools tend to optimise individual dimensions, such as immersion or collaboration, while rarely supporting integrated knowledge production. Three recurring tool profiles are identified, alongside systemic trade-offs between immersion and collaboration and visual fidelity and analytical depth. The article contributes a use-case matrix to synthesise the interrelations between interaction technologies, planning phases, stakeholder configurations, and participatory objectives for more inclusive and transparent urban planning.

Keywords

co-creation; digital planning; extended reality; interaction technologies; participation

1. Introduction

The rapid development of digital planning has expanded the range and diversity of knowledge that can be mobilised in planning processes (Batty & Yang, 2022). While early digital planning tools, such as those based on CAD and GIS, were developed for individual planning experts, a growing set of interaction technologies, including extended reality (XR), tangible user interfaces (TUIs), and hybrid co-creation environments bridging analogue and digital interfaces, are emerging as mediators of collaborative and participatory planning practices (Othengrafen et al., 2025). These tools are embedded in co-creation processes ranging from participatory design workshops and digital platforms (Chassin et al., 2022; Imam et al., 2021; Lin & Benneker, 2022) to scenario-based planning and community-led development initiatives (Alonso et al., 2018; Seo, 2022). At the policy level, initiatives such as the New European Bauhaus and the New Leipzig Charter (Federal Ministry of the Interior, Building and Community, 2020) explicitly position co-creation as a key mechanism for addressing climate, social, and spatial challenges through more inclusive and multi-actor planning approaches.

Despite this growing technological landscape, the integration of digital tools into planning practice remains uneven. Many applications are presented primarily as demonstrations of technical capability, such as immersive visualisations (Simonofski et al., 2024), AI-generated scenarios (Othengrafen et al., 2025), or interactive environments (Nourian et al., 2024), yet planning practice lacks guidance on how these diverse, prototypical tools can be effectively compared or integrated into co-creative workflows (Billger et al., 2017). Existing research tends to focus either on individual technologies (Othengrafen et al., 2025), specific applications and case studies (e.g., Reaver, 2023), or process-oriented frameworks for digital participation (Gonçalves et al., 2026), leaving limited understanding of how interaction technologies compare across planning contexts, support different forms of knowledge, and structure participation. This gap is significant in urban planning, where decision-making is knowledge-intensive and socially mediated, relying on the interaction of analytical, experiential, local, and political knowledge to support representation, communication, negotiation, and shared reasoning among heterogeneous actors (Healey, 1997). As a result, existing evaluation approaches remain fragmented across disciplinary silos, and there is no coherent framework for understanding how interaction technologies structure inclusive co-creation in urban planning.

To address this gap, this article proposes an analytical framework to map emerging interaction technologies as mediators of spatial knowledge in co-creative planning processes. Building on participatory design theory and the “experiencing the future” framework (Dane et al., 2024), this work integrates and operationalises interaction qualities with dimensions of knowledge production, participation, and governance. Rather than an applied decision-making tool, the contribution is to provide researchers and practitioners with a systematic lens, synthesised in a use-case matrix, to compare how different XR and hybrid tools shape interaction, support distinct forms of spatial knowledge, and align with broader planning contexts. Three research questions guide the work:

RQ1: What interaction capabilities define current co-creation interaction technologies in urban planning?

RQ2: How do these capabilities structure participation, knowledge production, and trade-offs across tools?

RQ3: How can these relationships be operationalised into a structured use-case matrix linking technologies to planning practice?

The article is structured as follows (Figure 1). Section 2 reviews interaction technologies in urban planning and existing evaluation frameworks. Section 3 introduces the analytical framework and mapping methodology. Section 4 presents the mapping results and patterns across tools. Section 5 discusses implications for co-creative planning and develops a use-case matrix. Section 6 provides closing remarks.

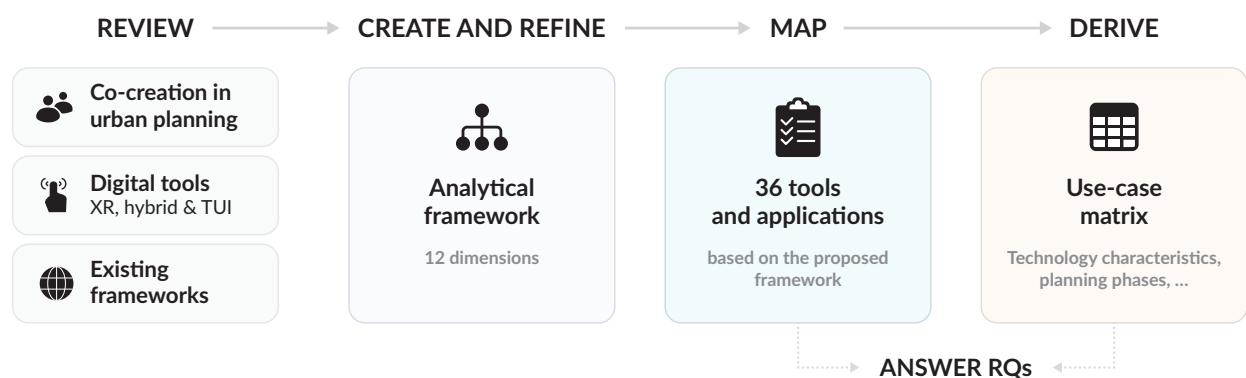


Figure 1. Overview of research design.

2. Background and Context on Digital Technologies in Urban Planning

Urban planning operates at the intersection of spatial and communicative practices. It concerns the physical organisation of space—urban form, land use, infrastructure, and environmental performance (Talen, 2002)—but it is also a process of negotiation and coordination among actors who interpret, evaluate, and shape these spatial decisions through different forms of knowledge (Davoudi, 2015; Healey, 1997) and power (Fainstein, 1999). These two dimensions are inseparable: Decisions about space are simultaneously decisions about whose knowledge counts, whose futures are represented, and whose interests are addressed. In this context, co-creation in urban planning serves two closely related purposes: (a) enabling inclusive participation and communication among stakeholders, and (b) supporting informed decision-making about future spatial development (Dane et al., 2024). This dual role places specific demands on the tools and methods used in planning processes.

2.1. Urban Planning and Digital Tools

Digital planning reflects a broader ambition to improve the sustainability, efficiency, inclusiveness, and evidence base of planning processes (Batty & Yang, 2022; Lin et al., 2025). This distinguishes it from planning support science, which focuses on how computational tools support specific tasks such as spatial analysis, modelling, and scenario comparison (Gil, 2020). While planning support science is primarily concerned with methodological and analytical support, digital planning is application-oriented, encompassing a wider range of interventions, including participatory platforms, immersive environments, and generative systems (Batty, 2021; Lin et al., 2025).

As the range of digital tools expands, however, the conceptual and methodological vocabulary for understanding their role in planning remains fragmented (Batty & Yang, 2022). Tools are often developed and evaluated within disciplinary silos, such as urban informatics, architectural computation, human-computer interaction (HCI), user experience (UX), or participatory design, with limited cross-disciplinary exchange. The result is a rapidly growing technology landscape without an integrative framework for assessing what tools enable within planning practice, and for whom.

2.2. Co-Creation, Participation, and Heterogeneous Knowledge

Participation and co-creation have become central to planning because planning problems require multiple actors, diverse forms of knowledge, and collaborative exploration of alternatives (Healey, 1997). Co-creation, as developed in participatory design research, extends beyond consultation to collective creativity across inquiry, analysis, ideation, and decision-making (Sanders & Stappers, 2008). In urban planning, this implies that participants must be able to understand the spatial and social consequences of design alternatives, compare scenarios, and contribute to decisions in meaningful ways (Gaete Cruz et al., 2022).

Participation theory further highlights that engagement varies not only in the degree of stakeholder influence but also in who participates, how participants interact, and how decisions are made. Arnstein's (1969) ladder conceptualises participation as a continuum of increasing citizen influence, while Fung's (2006) democracy cube broadens this perspective by considering participant selection, modes of communication, and decision authority. Wilcox (1994) distinguishes purposes and forms of participation, ranging from information sharing to supporting independent community action. Together, these frameworks suggest that participation is inherently multidimensional, which aligns with recent work on co-creation in urban planning. D. Lee et al. (2024) argue that co-creation should be characterised not only by who participates, but also by why they participate, what they contribute, what is produced, at which planning phase, through which means, and in what context.

Visual collaborative methods are key to such engagement: Visual representations can function as a shared language between actors with different expertise, allowing non-designers to participate in spatial reasoning and collaborative decision-making (Sanders, 2009; Whyte et al., 2017). Co-design processes depend on tools that let participants explore and communicate their understanding of space in accessible, context-sensitive ways (Mueller et al., 2018). Planning tools must therefore not only represent spatial information accurately but also mediate across different knowledge types and support genuine collaborative inquiry rather than one-directional communication. Recent work further frames co-creation as collaborative governance and knowledge production, reinforcing its role in activating, negotiating, and making diverse forms of knowledge actionable (Dane et al., 2024; Frantzeskaki et al., 2025).

2.3. Interaction Technologies for Co-Creation in Urban Planning

Within this context, a range of interaction technologies shows potential to support co-creation in planning processes, as exemplified in Figure 2. XR, encompassing augmented reality (AR), virtual reality (VR), tabletop, web/desktop, and projection, offers distinct capabilities for spatial visualisation, scenario exploration, and embodied engagement with design proposals (Skarbez et al., 2021). Desktop tools rely on conventional two-dimensional screens and offer the lowest level of immersion. AR overlays digital content onto the

physical environment, supporting contextual awareness and site-specific communication. VR provides fully immersive environments for experiencing and navigating future spatial scenarios (Laato et al., 2024). TUIs and hybrid co-creation environments represent a complementary approach (Minopoulos & Psannis, 2022). By linking digital models to physical artefacts and interactive surfaces, these systems support co-located, multi-user interaction, particularly in workshop settings, enabling shared spatial reasoning and allowing groups to manipulate and negotiate representations collectively in ways screen-based tools do not readily afford (Mueller et al., 2018). Across this continuum, differences in immersion, interactivity, and embodiment shape how users relate to spatial information and participate in planning discussions (Billger et al., 2017).

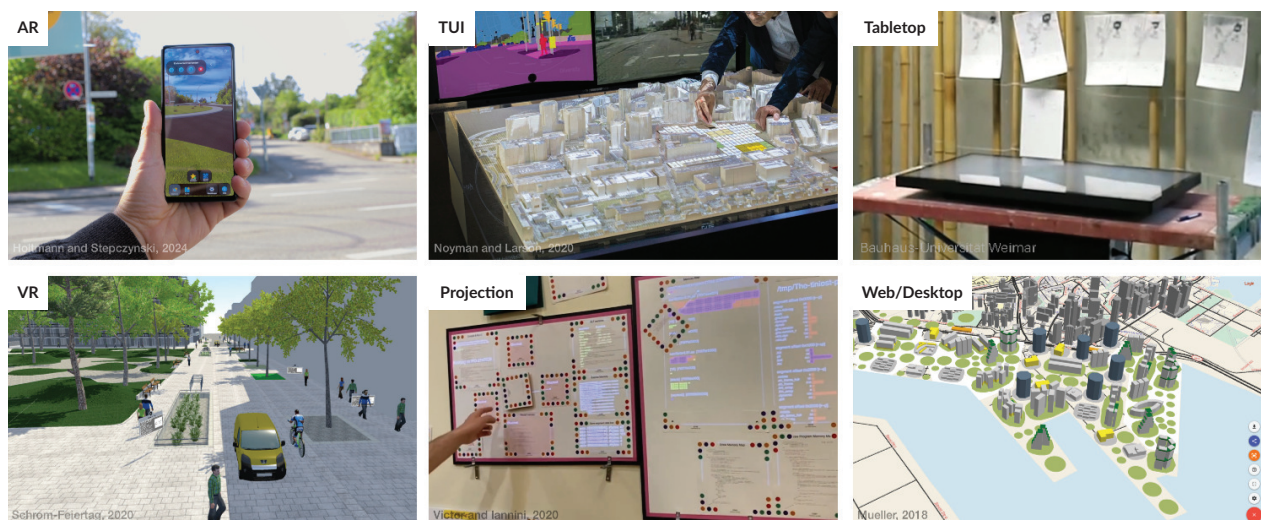


Figure 2. Overview of different technologies used in urban planning co-creation: (a) AR (Holtmann et al., 2024); (b) TUI (Noyman & Larson, 2020); (c) Tabletop (Bauhaus-Universität Weimar, n.d.); (d) VR (Schrom-Feiertag et al., 2020); (e) Projection (Victor et al., 2020); and (f) Web/Desktop (Mueller et al., 2018).

Despite their potential, interaction technologies in urban planning face a persistent limitation. Many tools are oriented toward representation and communication rather than active co-creation. Immersive visualisation tools are often developed to show stakeholders what future proposals might look like, but do not let them shape those proposals (Billger et al., 2017). The gap between tools that communicate plans and tools that support their collaborative creation remains substantial.

2.4. Review of Evaluation Approaches for Existing Digital Technologies

Existing approaches to evaluating digital technologies reflect this fragmentation. In this regard, we identify four main perspectives, namely technical performance and functional capability, multi-criteria evaluation, user-centred evaluation, and planning-oriented assessments.

The first treats planning tools primarily as technical systems, focusing on capabilities rather than their role in planning processes. Behmanesh and Brown (2019), for example, assess tools such as Esri CityEngine, Modelur, and Space Syntax in terms of data collection, analysis, modelling, and visualisation. Similarly, Eldrandaly (2007) applies ISO/IEC 9126 criteria, including functionality, usability, reliability, and cost, to evaluate GIS software. Hanan and Carhart (2025) evaluate participation-oriented tools against functional characteristics.

Regarding multi-criteria evaluation, Bataineh et al. (2018) compare CAD tools on criteria such as ease of use, cost, system requirements, and user satisfaction, focusing on single-user interaction rather than collective processes of collaboration and decision-making. Ul Hussnain et al. (2020) identify barriers to adoption such as data availability, workflow integration, and user-friendliness, similarly framing these as implementation challenges rather than as questions about how tools shape knowledge and participation. Malakhatka et al. (2025) proposed a five-layer framework that integrates UX with affordances such as realistic sensory immersion, dynamic information processing, and natural interaction modalities.

User-centred evaluation offers another angle informed by international standards defining usability as effectiveness, efficiency, and satisfaction (ISO 9241-11:2018) and UX as users' perceptions and responses during product interaction (ISO 9241-210:2019). In XR research, these concepts are difficult to operationalise consistently, as immersive environments introduce additional factors such as presence, embodiment, and simulator sickness (Cheiran et al., 2025; H. Lee, 2025). Recent UX models and questionnaires attempt to address this gap, but they primarily assess individual experience rather than collective knowledge exchange (Gkoumas et al., 2025). However, for co-creative urban planning, the key question is not only whether a tool is usable, but whether it enables heterogeneous actors to jointly interpret, negotiate, and act on spatial knowledge.

Finally, planning-oriented research addresses complementary concerns. Hasler et al. (2017) examine digital tools in relation to data generation and use, while Gaete Cruz et al. (2022) explores how visualisation shapes communication. Sousa & Paio (2021) integrate technical characteristics with planning-process fit. Kahila-Tani et al. (2019) demonstrate how public participation GIS (PPGIS) acts as a flexible, top-down tool to gather large-scale experiential data across varying planning phases. The most comprehensive recent attempt to connect tool design with practice is Gonçalves et al. (2026), who analyse 14 tools through planning stages, citizen roles, and HCI empowerment dimensions. However, they focus on web-based and platform tools, without addressing interaction qualities like immersion and spatial fidelity that distinguish XR and hybrid tools. The present framework extends this work by integrating these qualities to explain why different tool types produce distinct participation profiles.

To sum up, a key limitation remains: Existing approaches define usability inconsistently and focus on individual interaction rather than collective processes. They assess whether a tool can be used efficiently, but rarely whether it enables heterogeneous actors to co-create, negotiate, and act on spatial knowledge. As a result, the social and epistemic conditions of co-creation (whose knowledge becomes visible, how knowledge types are integrated, and what forms of reasoning are enabled) remain largely outside existing evaluation frameworks. This highlights the need to evaluate interaction technologies by how they structure knowledge production, participation, and decision-making in co-creative planning.

3. Framework Design Methodology

Existing approaches to evaluating digital technologies in urban planning remain fragmented. Technical frameworks focus on system performance, user-centred approaches emphasise individual experience, and planning-oriented studies address participation and visualisation, but rarely link these to interaction design and knowledge production. There is no coherent framework for assessing how interaction technologies shape co-creative planning. To bridge this gap, this article builds on the conceptual foundation

established by the “experiencing the future” framework developed by Dane et al. (2024), adopting its five foundational principles for effective co-creative environments, yet extending its utility by translating its primarily design-oriented focus into actionable, operational criteria for systematic tool evaluation across diverse contexts.

3.1. Framework Dimensions

This study operationalises these five principles (here referred to as “groups”) as aggregators of specific analytical dimensions (Sections 3.1.1–3.1.5). We extend Dane’s et al. (2024) framework by adding participation and transparency (Section 3.1.6), as key aspects of knowledge governance, as well as empirical user validation (Section 3.1.7), capturing whether tools report UX findings. Interaction technologies are thus conceptualised as mediators of spatial knowledge, shaping what can be represented, how users engage, and how knowledge is produced and negotiated in planning processes. Figure 3 represents the framework design. The following paragraphs detail the 12 dimensions (d1–d12) of the proposed framework, describe their organisation into seven groups, and explain how tools are classified within each dimension (see Figure 3 for a high-level representation).

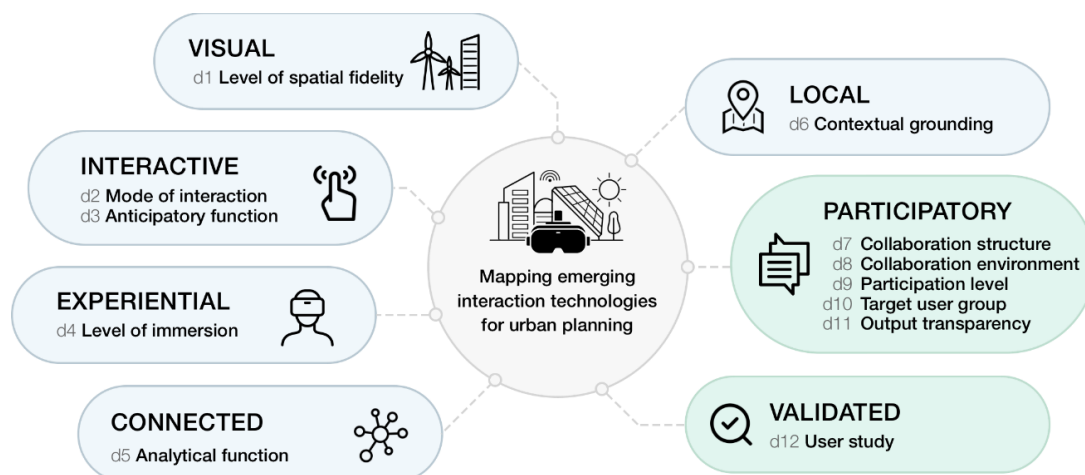


Figure 3. Proposed framework, adapted from the “experiencing the future” framework (Dane et al., 2024), for evaluating interaction technologies in the context of co-creation processes in urban planning.

Together, these dimensions enable a structured comparison of interaction technologies in co-creation contexts. Rather than ranking tools, the framework enables identification of patterns, complementarities, and gaps across technologies. By extending participatory design principles into an analytical structure, the approach allows tools to be compared in terms of their technical characteristics, as well as their capacity to support inclusive, transparent, and knowledge-rich planning processes.

3.1.1. Make It Visual

The first group addresses the representational capacity of interaction technologies. Building on Sheppard and Meitner’s (2005) and Sheppard’s (2012) work on visualisation in planning, “making it visual” reflects the ability of tools to communicate spatial information in accessible, interpretable, and meaningful ways for diverse stakeholders. It is operationalised through the (d1) spatial fidelity dimension, ranging from abstract

representations (e.g., diagrams or simplified maps), through schematic models, to highly detailed and realistic visualisations.

3.1.2. Make It Interactive

This group concerns the degree and nature of user interaction. It is operationalised through two distinct dimensions: (d2) mode of interaction and (d3) anticipatory function. “Mode of interaction” distinguishes three tool types: observational tools, presenting information without modification; manipulative tools, allowing users to modify existing elements; and generative tools, enabling the creation of new spatial configurations or scenarios (Wang et al., 2025). “Anticipatory function” captures whether a tool can test “what-if” situations, compare alternatives, and explore potential outcomes (Sheppard & Meitner, 2005). This is central to planning practice, where decisions are inherently future-oriented and uncertain (Campbell, 2012).

3.1.3. Make It Experiential

This dimension captures the experiential qualities of interaction technologies and is operationalised through (d4) level of immersion, which reflects the immersive potential of a medium within the reality–virtuality continuum (Skarbez et al., 2021) and ranges from screen-based interaction (categorised as Desktop), to AR, fully immersive environments such as VR, and hybrid and tangible tools (TUI). From a planning perspective, this group relates to *experiential knowledge*, a distinct and often underrepresented form of knowledge in planning processes (Healey, 2007).

3.1.4. Make It Connected

This dimension refers to the ability of tools to connect and overlay different types of information. In urban planning, this involves linking spatial representations with interdisciplinary data, analytical models, and broader urban systems, which is crucial to a holistic understanding. This dimension captures the (d5) analytical function of tools—their capacity to support understanding of existing conditions through data processing, interpretation, and comparison (Davoudi, 2015; Rydin, 2007). Tools are classified as high, medium, or low based on their capacity to integrate and analyse data across domains.

3.1.5. Make It Local

This dimension addresses the extent to which interaction technologies are grounded in a specific spatial and social context. Dane et al. (2024) emphasise that effective co-design requires a place-based approach, where representations and scenarios are linked to actual environments and locally relevant challenges. Contextual grounding (d6) refers to whether a tool structurally depends on site-specific data (e.g., building-level BIM, live municipal GIS, a city’s open-data infrastructure) to function, rather than operating on generic or placeholder content. A generic tool demonstrated at a real site is therefore not grounded. For example, Ariko’s architecture is built to accommodate any context.

3.1.6. Participatory Dimensions

This group extends Dane et al.'s (2024) framework by explicitly addressing participation and knowledge governance. Drawing on participation theory (Arnstein, 1969; Fung, 2006; Wilcox, 1994), it treats participation as a multidimensional construct encompassing stakeholder influence, interaction structure, collaboration environment, target users, and transparency. While interaction technologies can enable engagement, they differ significantly in how they structure participation and distribute agency among stakeholders. This group consists of five dimensions.

Collaboration structure (d7) describes how users interact with the technology. It is operationalised in three categories: simultaneous, where two or more participants interact with the technology together at the same time; sequential, where the technology is intended to be used by multiple participants within a session, but only one user interacts at a time, with others observing or awaiting their turn; and single-user, where the tool is designed for individual interaction, either with others present as passive observers or for asynchronous use by individuals (Birt & Vasilevski, 2021).

Collaboration environment (d8) describes the spatial configuration in which interaction takes place. It distinguishes between co-located environments, where participants engage in the same physical space; distributed environments, where they interact remotely; and hybrid environments, which combine both co-located and remote participation simultaneously. This dimension is relevant to how tools support communication, coordination, and inclusivity across planning contexts.

Participation level (d9) captures the degree of stakeholder influence (high–low). Building on recent work on digital participation (Hasler et al., 2017), this dimension spans a continuum from one-way information provision, consultation, and contribution to collaborative co-design and shared interaction. This perspective reflects a shift from static models of participation toward interaction-based understandings suited to digital environments.

Target user group (d10) captures whether interaction technologies are designed for expert users (e.g., planners, designers, technical specialists), for citizens and non-expert participants, or for both groups. This distinction is important, as different user groups require different levels of guidance, interface complexity, and forms of interaction, which in turn shape how knowledge is produced and communicated within co-creation processes.

Output transparency (d11) refers to the extent to which the processes and results generated by a tool are interpretable and exposes underlying data, assumptions, or model logic. Transparent tools qualified as high make underlying assumptions, data sources, and analytical processes visible, enabling participants to critically engage with outputs (Hasler et al., 2017). In contrast, tools qualified as low reinforce asymmetries in knowledge and power, thus limiting meaningful participation (Baibarac & Petrescu, 2019; Fainstein, 1999).

3.1.7. Supporting Evaluation and Iteration of Interaction Technologies

Finally, the user study (d12) addresses the extent to which technologies are evaluated with target user groups. Building on Baibarac and Petrescu (2019), effective co-creation environments are not static but evolve through feedback and user interaction. This dimension captures whether tools are evaluated with users—according to

UX metrics such as usability, efficiency, satisfaction, and cognitive load, as well as additional immersive aspects such as presence and embodiment (Gkoumas et al., 2025)—and supported by empirical evidence (yes or no).

3.2. Mapping Methodology

Relevant tools and applications were identified through a structured screening process. Building on the literature review, 92 publications together with selected grey literature and commercial sources were examined to extract examples of XR applications, tangible and hybrid co-creation tools, and related technologies used in urban planning contexts. Inclusion was guided by the following criteria: (a) The tool supported visualisation, simulation, co-design, or participatory communication in an urban planning or closely related context; (b) documentation characterised representation, interaction, and analytical properties; and (c) it had been demonstrated or reported in a co-creation or participatory setting. Based on these criteria, a shortlist of 45 tools was selected for in-depth analysis.

Tools were excluded if information was too sparse to support consistent coding, if they were mainly web/desktop-based without a co-creation orientation, or if they had been discussed as potentially relevant for such use cases but not yet demonstrated. Similarly excluded were technologies for citizen sensing and public feedback, such as interactive polling displays (Coenen et al., 2019) and wearable, location-based feedback apps (Wilson et al., 2019), which gather opinions about the existing environment and can inform co-creation as a data source. To balance the predominance of research prototypes in the literature, a small number of commercial tools repeatedly referenced in the literature were included. The selection thus proceeded in three steps: 92 sources screened, 45 tools shortlisted against criteria (a)–(c), and 36 tools retained in the final sample after consolidating closely related systems and removing tools whose documentation was too sparse. The sample is therefore not exhaustive but is intended to provide representative coverage of current approaches for co-creation in urban planning.

Each tool was coded using a deductive approach based on the proposed analytical framework. The coding scheme operationalised the framework dimensions and categories were defined prior to coding to avoid circularity between sample selection and framework dimensions; minor refinements were permitted only where recurring characteristics emerged that could not be accommodated by the existing scheme.

The coded data, presented in Figure 4, were synthesised in a comparative matrix to identify patterns across tool types. The analysis focuses on how technologies support specific forms of interaction, knowledge production, and participation, and where gaps or imbalances occur. The analysis identifies recurring patterns to inform future tool application.

Tool	VISUAL	INTERACTIVE		EXPERIENTIAL	CONNECTED	LOCAL	PARTICIPATORY					VALIDATED	
	d1 Spatial fidelity	d2 Mode of interaction	d3 Anticipatory function	d4 Level of immersion	d5 Analytical function	d6 Contextual grounding	d7 Collaboration structure	d8 Collaboration environment	d9 Level of participation	d10 Target user group	d11 Output transparency	d12 User study	
AIT Hybrid Planner	Schematic, High-fidelity	Manipulative	Yes	TUI, VR	High	Yes	Simultaneous	Co-located	High	Citizens	Experts	High	Reported
AR Urban Design Pedagogy	Schematic	Observational	No	AR	Medium	Yes	Simultaneous	Co-located	Medium	Citizens	Experts	High	Not reported
Arkio	Schematic, High-fidelity	Generative	No	VR, AR, Desktop	Low	No	Simultaneous	Distributed	High		Experts	Low	Not reported
Augmented Reality Sandbox	Abstract	Manipulative	No	Projection	Low	No	Simultaneous	Co-located	High	Citizens		Low	Not reported
Bauhaus-Univ. Urban Planning Table	Schematic	Manipulative	Yes	Tabletop	Medium	No	Simultaneous	Co-located	High	Citizens	Experts	High	Informal
Block by Block	Schematic	Generative	No	Desktop	Low	No	Simultaneous	Co-located	High	Citizens	Experts	High	Informal
Citizen Design Science	Schematic	Manipulative	No	Desktop	Low	No	Single	Distributed	Medium	Citizens	Experts	High	Not reported
City Blocks	Schematic	Manipulative	Yes	VR, TUI	Medium	No	Single	Co-located	Medium	Citizens	Experts	Low	Reported
City Craft	High-fidelity	Manipulative	No	AR	Low	Yes	Simultaneous	Co-located	High	Citizens	Experts	High	Reported
CityScope	Schematic, Abstract	Manipulative	Yes	TUI	High	No	Simultaneous	Co-located	High	Citizens	Experts	High	Not reported
CoHeSIVE	Abstract	Generative	No	VR	Low	Yes	Sequential	Co-located	High	Citizens	Experts	Low	Reported
COUP-XR	Schematic	Manipulative	Yes	TUI, VR	High	Yes	Simultaneous	Hybrid	High	Citizens	Experts	High	Reported
DeepScope	Schematic	Manipulative	No	TUI	Low	No	Simultaneous	Co-located	Medium	Citizens	Experts	Low	Informal
DIPAS	Schematic	Manipulative	Yes	TUI	Medium	Yes	Simultaneous	Hybrid	High	Citizens	Experts	High	Reported
Dynamicland Realtalk	Abstract	Manipulative	No	Projection	Low	No	Simultaneous	Co-located	High	Citizens	Experts	High	Not reported
Geospatial TUI Framework	Schematic	Manipulative	Yes	TUI	High	Yes	Simultaneous	Co-located	High	Citizens	Experts	High	Reported
GLARA	High-fidelity	Observational	Yes	AR	Medium	Yes	Single	Co-located	Medium	Citizens	Experts	High	Reported
GTUI	Schematic	Manipulative	Yes	TUI	Medium	Yes	Simultaneous	Co-located	Medium	Citizens	Experts	Low	Not reported
inCituAR	High-fidelity	Observational	No	AR	Low	Yes	Single	Hybrid	Low	Citizens	Experts	Low	Not reported
Inspirer	High-fidelity	Manipulative	No	VR, AR	Low	Yes	Single	Co-located	Medium	Citizens	Experts	Low	Reported
MR Digital Twin Simulation	High-fidelity	Observational	No	AR	Medium	Yes	Sequential	Co-located	Medium		Experts	Low	Not reported
MR Tent	Schematic	Manipulative	No	AR, TUI	Low	Yes	Simultaneous	Co-located	High	Citizens	Experts	High	Reported
superbarrio	Schematic	Manipulative	Yes	AR, Desktop	Medium	Yes	Simultaneous	Distributed	Medium	Citizens	Experts	High	Informal
Tangible 3D Urban Sim. Table	Schematic	Manipulative	Yes	TUI	Medium	Yes	Simultaneous	Co-located	Low	Citizens	Experts	High	Not reported
Tangible Landscape	Schematic	Manipulative	Yes	TUI	Medium	Yes	Single	Co-located	Low		Experts	High	Reported
Tangible Windmills	Schematic	Manipulative	Yes	TUI	Medium	No	Single	Co-located	Low		Experts	High	Reported
UCODE	Schematic	Manipulative	No	Desktop	Medium	Yes	Simultaneous	Distributed	High	Citizens	Experts	Low	Informal
Urban CoCreation Lab	Schematic	Manipulative	Yes	VR, AR, Desktop	Medium	Yes	Simultaneous	Hybrid	High	Citizens	Experts	High	Reported
Urbanistic	Schematic	Generative	No	VR, Desktop	High	No	Sequential	Hybrid	Low		Experts	High	Not reported
UrbanPlanAR	High-fidelity	Observational	No	AR	Low	Yes	Single	Co-located	Low	Citizens	Experts	Low	Not reported
Vivid Hydrodynamic Sandbox	Abstract	Manipulative	No	Projection	Low	No	Simultaneous	Co-located	High	Citizens		Low	Informal
VR Park Participation	High-fidelity	Observational	No	VR	Low	Yes	Single	Hybrid	High	Citizens		High	Reported
VR Traffic Simulation	High-fidelity	Manipulative	Yes	VR	Medium	Yes	Sequential	Co-located	Medium	Citizens	Experts	High	Reported
WebVRGIS Smart City	High-fidelity	Observational	Yes	Desktop	High	Yes	Simultaneous	Distributed	Low		Experts	High	Reported
WebXR for Urban Planning	Schematic, High-fidelity	Observational	No	AR, VR	Medium	Yes	Single	Hybrid	Medium		Experts	High	Reported
XR for Transf. and Interactive Design	High-fidelity	Manipulative	No	VR, AR	Low	Yes	Simultaneous	Hybrid	Low		Experts	Low	Reported

Figure 4. Detailed mapping results: Rows correspond to the 36 reviewed tools and columns to the 12 framework dimensions. Notes: Grey cells: categorical values; Green cells: ordinal values, with darker shades indicating higher levels.

4. Results

4.1. Overview of Mapped Tools

Thirty-six tools and applications were mapped and coded across the 12 framework dimensions. The sample covers six modality types (see Figure 5): 13 tools incorporate AR, 12 VR, 12 TUI-based tangible and hybrid interaction, eight web- or desktop-based platforms, three projection-based systems, and one tabletop interface. Counts overlap because most tools are coded for more than one modality. Figure 6 summarises the mapped dimensions. Twenty-eight tools (78%) are research prototypes; the remaining eight (22%) are commercially and/or operationally deployed. Publication years range from 2012 to 2025 and mostly after 2018, reflecting a rapidly expanding field. Nineteen tools report on formal user studies, six report only informal evaluations, and the remaining 11 report none. This uneven evidence base suggests that technical development has often preceded systematic evaluation of planning outcomes. Results are drawn from dimensional coding, with individual tool names used where illustrative of broader patterns.

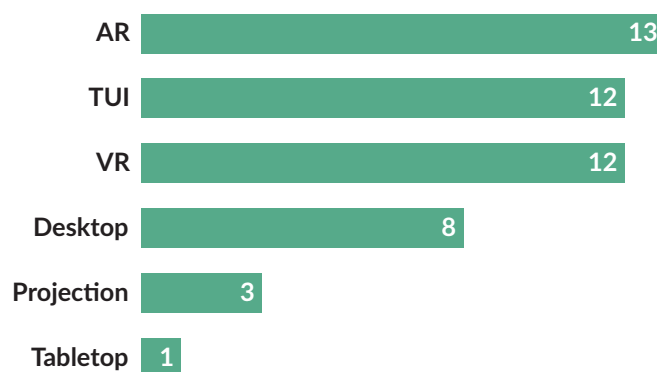


Figure 5. Distribution of the sampled tools across five broad interaction-modality types.

The following results are organised into three analytical groupings that aggregate the 12 framework dimensions for clarity of presentation. Section 4.2 addresses interaction capabilities, drawing on the make it visual (d1), make it interactive (d2, d3), make it experiential (d4), and make it connected (d5) groups. Section 4.3 addresses the participation level (d9) and output transparency (d11) dimensions, which showed the most analytically significant variation across the sample. Section 4.4 addresses contextual grounding (d6) and planning phase fit. Dimensions with more uniform distributions across the sample, including collaboration structure (d7) and environment (d8), target user group (d10), and user study (d12), are reported in the mapping matrix (Figure 4) and discussed where patterns are relevant.

VISUAL	INTERACTIVE		EXPERIENTIAL	CONNECTED	LOCAL	PARTICIPATORY					VALIDATED
d1 Spatial fidelity	d2 Mode of interaction	d3 Anticipatory function	d4 Level of immersion	d5 Analytical function	d6 Contextual grounding	d7 Collaboration structure	d8 Collaboration environment	d9 Participation level	d10 Target user group	d11 Output transparency	d12 User study
High-fidelity	Generative	Yes	VR	High	Yes	Simultaneous	Hybrid	High	Citizens	High	Reported
	Manipulative		AR	Medium			Distributed				
Schematic		No	TUI	Low			Sequential	Co-located	Medium	Experts	Low
			Projection			Single	Low		Not reported		
Abstract	Observational			Desktop		No					

Figure 6. Aggregated overview of the mapping result across the 12 framework dimensions. Notes: Grey cells: categorical values; Green cells: ordinal values, with darker shades indicating higher levels.

4.2. Interaction Capabilities: Make It Visual, Interactive, Experiential, and Connected

4.2.1. Mode of Interaction and Anticipatory Function

The dominant interaction mode across the sample is manipulative, with 24 of 36 tools (67%) allowing users to configure or rearrange existing spatial elements within a predefined system. Eight tools are purely observational, meaning that they only allow users to passively engage with content (primarily visually). Only four tools support generative interaction, enabling users to produce new spatial configurations within the constraints of the system. This distribution indicates that most tools enable manipulation within predefined systems, while generative interaction remains limited.

Structured scenario exploration, the anticipatory function of the framework, is less common than the high rate of manipulative interaction might suggest. Only 10 of 36 tools (28%) explicitly support comparative what-if scenarios with quantified outcome feedback. These tools are concentrated in TUI-based and analytically connected platforms. Within the sample, no tool with low analytical function supports anticipatory reasoning, indicating that scenario comparison is associated with prior data integration. Interaction mode and analytical function thus appear to be co-determining rather than independent dimensions.

4.2.2. Spatial Fidelity and Experiential Quality

Spatial fidelity is unevenly distributed across the sample: 14 tools, almost entirely in AR and VR, feature high-fidelity rendering; 18 operate at a schematic level; and four use abstract or diagrammatic representations. Notably, of the 14 high-fidelity tools, eight (57%) score low on analytical function (see, for example, Figure 7). This pattern shows that high-fidelity tools are often associated with lower analytical function integration. Similarly, immersion splits along modality lines: AR and VR tools prioritise experiential quality and a sense of spatial presence, while TUI and projection tools prioritise synchronous multi-user tangible interaction, typically at schematic fidelity. Immersion and collaboration format are negatively correlated across the sample, a pattern examined further in the Discussion (Section 5).

Inspirer VR/AR		
Spatial fidelity		High-fidelity: photorealistic representation of the planned project; the VR scene is constructed from 3D point-cloud scans, 3D city maps, and converted 3D models
Mode of interaction		Manipulative: users place pre-fabricated virtual objects in the scene, perform freeform three-dimensional drawing, and submit ratings and text comments on the visualised proposal
Anticipatory function		Single planned proposal is visualised; the tool does not support comparison of named alternative scenarios with quantified outcomes
Level of immersion		VR demonstrator and smartphone-based AR app
Analytical function		Single-domain spatial visualisation of the proposal; no environmental, traffic, or other performance-data layers are reported alongside the model
Contextual grounding		Co-developed with the city of Fellbach; the case study addresses the planned conversion of a specific intersection into a roundabout
Collaboration structure		Individual use of AR and VR demonstrators; no concurrent multi-user mode reported
Collaboration environment		Co-located
Participation level		Participants contribute ratings and comments
Target user group		Qualitative evaluation with 16 citizens; requirements phase included 11 interviews with planning-process stakeholders
Output transparency		Users see the final visualised state of the planned project
User study		16 semi-structured interviews; no standardised UX scales were reported

Figure 7. Example VR tool profile: Inspirer. Notes: Grey cells: categorical values; Green cells: ordinal values, with darker shades indicating higher levels.

4.2.3. Analytical Function

Fourteen tools (39%) have low analytical function, offering spatial representation without any quantitative data layer. Sixteen (44%) integrate at least one environmental, traffic, or performance domain. Only six tools achieve high analytical function, combining two or more distinct data or simulation domains simultaneously: CityScope, COUP-XR, the Geospatial TUI Framework, DIPAS, AIT Hybrid Planner (Figure 8), and WebVRGIS Smart City.

To summarise, the interaction capability findings indicate three tool profiles. The first, including most AR tools and several VR tools, is characterised by observational or lightly manipulative, high-fidelity, low analytical qualities. The second concerns primarily TUIs and hybrid platforms and shows manipulative, schematic, multi-user, and medium-to-high analytical traits. The last cluster of integrated platforms combines high analytical function with high participation. These three profiles structure the results that follow and provide the basis for the use-case alignment developed in the Discussion (Section 5).

AIT Hybrid Planner TUI/VR



Spatial fidelity	Schematic abstraction paired with photorealistic rendering; OpenStreetMap data and Google 3D tiles for site context
Mode of interaction	Manipulative: participants arrange paper cutouts of programmatic elements on a printed site map
Anticipatory function	Each cutout configuration is a what-if scenario evaluated with selected KPI against others
Level of immersion	Combining tangible paper cutouts on a printed site map with high-fidelity rendering of the resulting design
Analytical function	Urban cooling simulation, PED simulation, and space usage statistics run in parallel
Contextual grounding	Real-world site data as the basis for the simulation model and visualisation
Collaboration structure	Workshop format in which multiple participants concurrently arrange cutouts on a shared site map; reported group sizes range from five to 30 per session
Collaboration environment	Co-located
Participation level	Participants co-create the proposal by physically placing cutouts on the shared site map
Target user group	Workshops included both non-expert participants and design professionals
Output transparency	KPI panels show simulation results and allow participants to relate specific design choices to performance changes
User study	Eight workshops with 5-30 participants per session; structured surveys and group discussion

Figure 8. Example hybrid/TUI tool: AIT Hybrid Planner. Notes: Grey cells: categorical values; Green cells: ordinal values, with darker shades indicating higher levels; KPI = Key Performance Indicator; PED = Pedestrian dynamics simulation. Source: Adapted from Sandor et al. (2025).

4.3. Participation and Transparency: Participatory Dimensions

4.3.1. Participation Levels

Seventeen tools (47%) are coded as collaborative, enabling genuine co-creation with meaningful stakeholder agency over spatial outcomes. Twelve (33%) operate at a consultative level, in which stakeholder input is collected but decision authority remains with experts. Six tools (17%) provide informative or observational engagement only. The overall distribution appears relatively favourable toward co-creation, but other dimensions have to be reviewed together to verify the outcomes.

The high collaborative count masks a strong modality dependency. Most collaboratively coded tools are TUIs, projections, or hybrid systems, where simultaneous multi-user tangible manipulation is associated with joint spatial reasoning. AR visualisation tools are concentrated at consultative or informative levels, delivering technically compelling spatial experiences but mostly relegating users to a passive role of audience rather than co-designers. Only a few of the 17 collaboratively coded tools are primarily AR or VR (e.g., CoHeSIVE, VR Park, and City Craft), suggesting a misalignment in the current tool landscape between immersive experiential quality and degree of participation. The tools that, through high fidelity and embodied presence, are most capable of communicating spatial futures to non-expert citizens are among the least capable of enabling them to shape those futures, while TUIs and hybrid platforms support genuine co-authorship but offer comparatively less immersive environments. CoHeSIVE (Evers et al., 2023) is a notable exception (see Figure 9), offering a high level of citizen-expert participation with predominantly low-fidelity VR immersion.

CoHeSIVE VR	
Spatial fidelity	Low-detail VR environment with limited textures
Mode of interaction	Generative: participants author design proposals in VR by selecting and combining pre-defined urban-design attributes
Anticipatory function	Participants go through a single proposal at a time
Level of immersion	Fully immersive head-mounted display experience navigated by VR controller
Analytical function	Single-domain spatial visualisation in VR
Contextual grounding	The case scenario is the future station plaza of downtown Eindhoven; VR environment built for that specific site
Collaboration structure	VR headset is passed between participants in workshop sessions
Collaboration environment	Co-located
Participation level	Participants co-create the proposal by physically placing cutouts on the shared site map
Target user group	Pilot participants included both citizens and experts
Output transparency	Participants see the configured VR scene
User study	Pilot study with 19 participants included UX ratings such as immersion, ease of use, and user acceptance

Figure 9. Example of contextualised, participative VR environment: CoHeSIVE. Source: Adapted from Evers et al. (2023). Notes: Grey cells: categorical values; Green cells: ordinal values, with darker shades indicating higher levels.

4.3.2. Output Transparency

Twenty-seven of 36 tools (75%) are coded as transparent, exposing data sources, simulation parameters, or model logic to participants. Six tools (17%) are opaque. The high overall transparency rate reflects the predominantly tangible and simulation-based character of the sample, where physical interaction with visible data layers is inherent to most TUIs (e.g., Tangible Windmills, DIPAS, or Tangible 3D Urban Simulation Table).

4.4. Contextual Grounding and Planning Fit: Make It Local and Contextual Applicability

Most of the mapped technologies (67%) are deployed in a specific real-world urban context, fitting the framework's local dimension. However, contextual grounding requires interpretation. A substantial portion of grounded tools were demonstrated at a research site while remaining architecturally generic (e.g., Block by Block); because we code the tool's design instead of its deployment, we treat these as not grounded. Only a subset requires place-specific data to function: tools tied to building-level BIM models, platforms that ingest live municipal GIS data (e.g., DIPAS), or systems built around a specific city's open data infrastructure. Eleven tools, like Ariko, DeepScope, and City Blocks, are contextually generic, developed as platform demonstrations independent of specific sites.

Planning phase coverage is markedly uneven. Most tools concentrate in preparatory exploration and early feasibility phases, where co-creation is most exploratory and least institutionally constrained. Only DIPAS explicitly supports formal planning and zoning, where decisions carry regulatory consequences and public participation is most often legally required. This points to a structural gap between technological development

and institutional integration: Tools are being built for the phases where creative engagement is expected, not where it is most consequential. Tools that are architecturally generic and phase-agnostic are moreover unlikely to meet the procedural conditions of formal planning stages, regardless of their interaction qualities.

5. Discussion

Results identify dominant interaction capabilities across tools and reveal systematic patterns and trade-offs in how these capabilities structure participation and knowledge production. These patterns form the basis for the discussion that answers the following research questions:

RQ1: Across the sample, 67% of tools are manipulative, 11% generative, and only 28% support anticipatory what-if reasoning; high-fidelity rendering (14 tools) is largely decoupled from analytical depth. Tools thus cluster into uneven capability profiles rather than offering balanced support across interaction qualities.

RQ2: The analysis reveals systematic patterns (Section 5.1) and trade-offs (Section 5.2), including a strong alignment between modality and participation level, as well as tensions between immersion and collaboration, fidelity and analytical depth. These patterns show structural profiles indicating that tools do not simply enable participation, but actively shape how knowledge is produced, shared, and used.

RQ3: Based on the identified tool profiles and trade-offs, this research proposes a use-case matrix (Figure 10) that aligns technologies with planning phases, stakeholder configurations, and participation objectives, emphasising the need for strategic combination rather than reliance on a single tool.

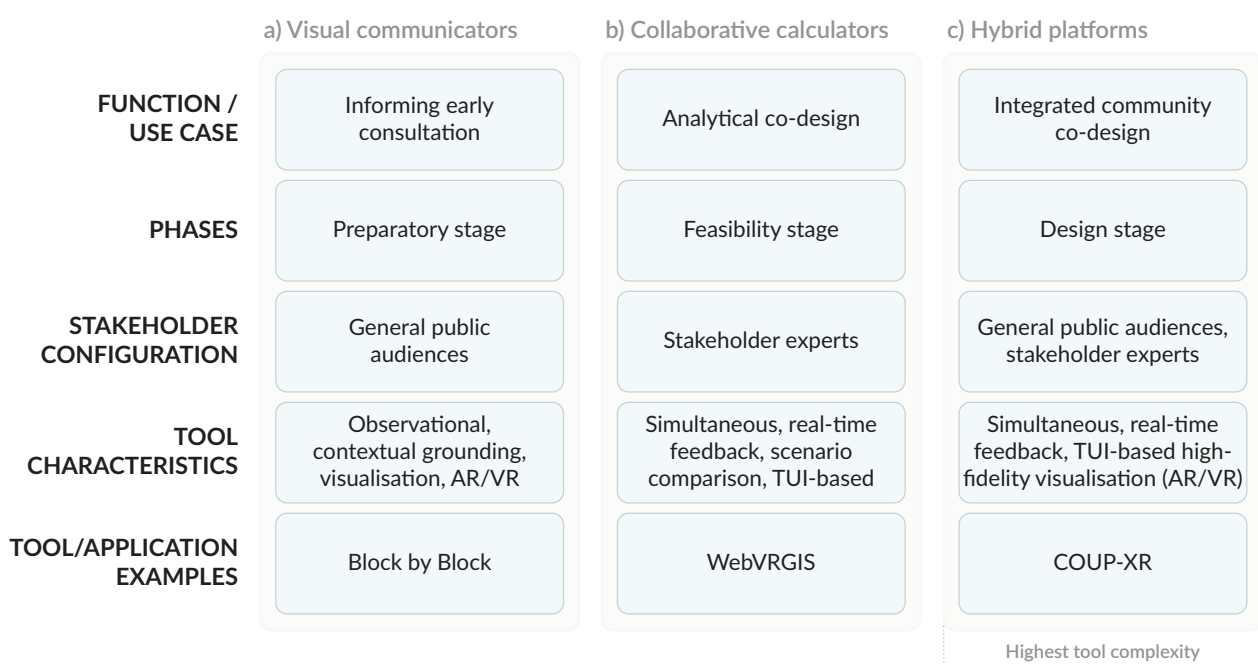


Figure 10. Diagram with use-case matrix showing (a) visual communicators, (b) collaborative calculators, and (c) integrated hybrid platforms.

5.1. Three Structural Profiles and Their Epistemic Implications

The results reveal three structurally distinct profiles, each representing a different resolution of the tension between experiential quality, analytical depth, and participatory capacity. Understanding them as coherent positions matters for how the field develops and how planners select tools for specific purposes.

The first profile, *visual communicators*, encompasses tools that are observational or lightly manipulative, high in spatial fidelity, low in analytical function, and consultative in participation level. These tools are effective at conveying spatial proposals in accessible and experientially compelling terms, particularly for non-experts. Their epistemic function is primarily representational: They extend what can be seen and sensed, but not what can be reasoned about or collectively shaped. While 3D visualisations and immersive environments boost public engagement and spatial awareness (van Leeuwen et al., 2018), these tools widen the reach of planning communication without expanding collaborative knowledge production (Healey, 1997). Experiential engagement does not equal analytical understanding or better decision-making (van Leeuwen et al., 2018). Moreover, extending Gonçalves et al.'s (2026) observation that citizens are positioned primarily as assessors, our analysis demonstrates that this limitation stems directly from interaction modality rather than design mindset alone.

The next profile, *collaborative calculators*, encompasses TUI and hybrid platforms that are manipulative, schematic in fidelity, simultaneous multi-user, medium-to-high in analytical function, and collaborative in participation. These tools represent the most epistemically capable configuration in the current landscape: They enable groups of heterogeneous actors to jointly explore spatial alternatives, receive quantified performance feedback, and negotiate outcomes in real time. Their limitation is experiential: Users engage with space as schematic abstraction, rather than as a place. The comparatively low immersion and fidelity of these tools may reduce their communicative reach with non-expert community participants for whom embodied spatial understanding is a primary mode of engagement (Dane et al., 2024).

However, high fidelity does not necessarily equate to usefulness. Research suggests that decision-support capacity is more critical than visual realism alone (Sandor et al., 2025), which may even hinder co-creation by shaping expectations, making proposals appear more finalised, and reducing participants' willingness to critique or propose alternatives. More abstract representations, by contrast, can help maintain openness in the design process, while static high-fidelity visuals may obscure temporal dynamics (e.g., showing trees at full maturity), leading to unrealistic expectations (Sandor et al., 2025).

The third profile, *integrated hybrid platforms*, combines immersive visualisation with collaborative tangible interaction and analytical simulation. These tools approach the full complement of framework dimensions, supporting high participation, high analytical function, contextual grounding, and experiential quality, as exemplified by systems such as COUP-XR (Holtorf & Noennig, 2025), which integrate tangible AR interaction with immersive VR environments and real-time simulation feedback. However, they do so at significant cost in setup complexity, hardware requirements, and expert facilitation, limiting their scalability beyond intensive, purpose-built workshop settings.

5.2. Systemic Trade-Offs as Design Constraints

Beyond these profiles, the mapping reveals three systemic trade-offs. They are not temporary limitations but reflect deeper design constraints that currently shape the evolution of digital planning tools.

5.2.1. Immersion–Collaboration Trade-Off

In most cases, immersive VR environments require sequential individual use, limiting the simultaneous shared engagement that co-design processes depend on. This appears to be a structural limitation of current head-mounted display configurations, in which each user is perceptually isolated from others. This trade-off is implicit in the findings of Gonçalves et al. (2026), where CoHeSIVE (the only VR tool in their sample) is also the only tool supporting co-creation (Testing & Experimentation stage), yet its immersive architecture constrains its collaborative potential. We theorise this pattern as a structural trade-off rather than an incidental feature of specific tools. TUIs and projection-based systems address the collaboration requirement precisely by foregoing individual immersion. No tool in the sample fully resolves this trade-off; hybrid configurations approximate a resolution, but at considerable cost in setup complexity.

5.2.2. Fidelity–Analysis Trade-Off

The negative correlation between high visual realism and high analytical depth across the sample indicates that these capabilities are competing priorities in tool development. This matters because they serve different knowledge functions—experiential understanding and evidence-based reasoning—both of which, according to Davoudi (2015) and Sheppard & Meitner (2005), are necessary for informed co-creation.

5.2.3. Participation–Complexity Trade-Off

The most collaboratively capable tools in the sample are also among the most demanding to deploy: They require expert facilitation, hardware setup, physical co-location, and prior data preparation. This creates an inverse relationship between participatory capability and accessibility: The tools that enable the deepest co-creation are not the most widely reachable. Organisations and communities with fewer institutional resources are more likely to rely on lower-threshold tools that, by design, support informative or consultative engagement rather than genuine co-production (Leino & Puumala, 2021). This is consistent with findings that digitally supported participation requires greater preparation, specialised expertise, and higher upfront costs compared to analogue approaches, even if they enable easier scaling and data management in later stages (Bizjak, 2012; Fessler et al., 2024). More broadly, co-design processes are inherently non-linear, resource-intensive, and complex to manage, despite their potential to deliver more inclusive and robust outcomes (Gaete Cruz et al., 2023).

5.3. Toward a Use-Case Matrix: Aligning Tool Profiles With Planning Practice

A central implication of the mapping is that no single tool or tool class satisfies all framework dimensions simultaneously. Planning processes, unfolding across multiple phases with shifting stakeholder configurations, require strategic combination of tools. This reinforces findings from Sousa and Paio (2021), which show that there is no universally optimal participatory tool, only context-dependent solutions aligned with planning stages, levels of engagement, and technical conditions.

Three broad use-case alignments emerge from the data. The first concerns informing and early consultation, directed at wide public audiences in preparatory and communication phases. AR observational and VR visualisation tools (e.g., Block by Block) are most appropriate here: Their strength in experiential function and spatial fidelity supports accessible communication of proposals to non-expert audiences, satisfying the framework's local and visual principles. Their consultative rather than collaborative character is acceptable here, where the primary objective is spatial comprehension rather than co-production. The dimensions most relevant to tool selection are experiential function, contextual grounding, and output transparency.

The second alignment concerns analytical co-design in expert and multi-stakeholder workshops during feasibility and design phases. TUI-based and analytically integrated platforms are most appropriate here, enabling simultaneous manipulation, real-time simulation feedback, and structured scenario comparison across actors with different disciplinary expertise (e.g., WebVRGIS Smart City). In Holtorf & Noennig (2025), participants valued perceiving how spatial changes affected urban dynamics, suggesting that the integration of simulation with interactive visualisation can support more intuitive forms of anticipatory reasoning.

The third alignment concerns integrated community co-design, typically at neighbourhood scale, in iterative participatory processes requiring both experiential engagement and genuine stakeholder agency. Hybrid platforms combining TUI-based input and AR/VR realistic visualisation output (e.g., COUP-XR) are most appropriate, though their deployment complexity requires institutional capacity and expert facilitation. This use case represents the highest demands on tool capability and organisational capacity, usually requiring more than one expert, and is currently underserved: Available systems are mostly research prototypes.

Several structural factors explain this gap. First, such systems are technically complex, requiring the integration of multiple interaction modalities, real-time data processing, and multi-user coordination. Second, most existing solutions remain research prototypes rather than commercial products, limiting accessibility and scalability. Third, their effective use depends on skilled facilitation and institutional readiness, which are not yet widely established in practice.

Together, these constraints suggest that the limited availability of integrated co-design platforms is not only a technological issue but also reflects broader organisational and market barriers. This has important implications for policy and practice, indicating that advancing co-creative urban planning requires also investment in institutional capacity, facilitation expertise, and the translation of prototype systems into deployable solutions.

These three alignments are not mutually exclusive but potentially overlapping moments in a single planning process. A comprehensive participatory workflow might deploy visual communicator tools for initial community engagement, transition to collaborative calculator platforms for analytical workshops, and use integrated hybrid environments for intensive co-design sessions as shown in Figure 10.

Importantly, previous research shows that the effectiveness of interaction technologies depends not only on data generation, but also on whether the resulting knowledge is integrated into planning and decision-making processes (Hasler et al., 2017). Dominant planning cultures and governance structures can limit the adoption of technological innovations, indicating that digital transformation requires changes in organisational practices as well as new tools (Lin et al., 2025). Even technologies that appear to enable high user control, such as

AR-based interaction, often require expert facilitation, highlighting that technological affordances alone do not guarantee meaningful participation (Reaver, 2023).

5.4. Limitations and Directions for Future Research

This study is based on desk research and documentary coding rather than empirical testing with users or planning stakeholders. The analysis reflects how tools are described and evaluated in the literature, not necessarily how they perform in the complex institutional and social conditions of real planning processes. Several tools in the sample have limited evaluation evidence, and the field is evolving at a pace that the literature does not always reflect. Additionally, the sample does not include AI tools or natural language conversational interfaces, which are emerging rapidly as distinct tool categories. The framework also does not capture the HCI empowerment dimensions foregrounded by Gonçalves et al. (2026), including the persistence of empowerment after tool use and the participatory or expert mindset of tool designers, which remain important complementary dimensions for future integration.

Moreover, the coding dimensions involve interpretive judgements in their application, particularly for participation level and experiential function, where it depends on contextual assumptions about user configuration and deployment setting. Future research should translate the conceptual and analytical insights into an actionable, field-ready toolkit and subject the framework to empirical validation through structured expert evaluation, practitioner application in real planning processes, and longitudinal assessment of tool outcomes in co-creative settings. Addressing the institutional barriers noted in Section 5.3 will also require practical measures such as facilitation training and clearer procurement pathways from prototype to deployment. The use-case matrix is an analytical starting point whose utility will be best tested and refined through application in practice.

6. Conclusion

This study examined how emerging interaction technologies shape co-creative processes in urban planning by conceptualising them as mediators of spatial knowledge. Mapping a sample of 36 identified technologies ranging from VR, AR, TUI to hybrid and tabletop through a structured analytical framework revealed the following key findings:

- Interaction technologies in urban planning are structurally fragmented, with most tools optimising isolated capabilities (e.g., immersion, collaboration, or analysis) rather than supporting integrated co-creation.
- Most tools position citizens as assessors rather than co-designers (Gonçalves et al., 2026); the present analysis extends this finding by showing that interaction modality is the primary structural determinant of citizen role, with TUI and hybrid platforms consistently enabling higher participation levels than immersive XR environments.
- Three distinct tool profiles emerge—visual communicators, collaborative calculators, and integrated hybrid platforms—forming a use-case matrix that relates technologies to planning phases, stakeholder configurations, and participation objectives, providing an analytical basis for comparing and combining tools across planning contexts. Systemic trade-offs (immersion–collaboration, fidelity–analysis, participation–complexity) act as design constraints, shaping how tools mediate participation and limiting their combined effectiveness.

- No single tool satisfies all co-creation requirements, highlighting the need to combine complementary technologies across planning phases according to participation goals, stakeholder configurations, and analytical requirements.
- Integrated, high-capability co-design platforms remain rare, due to technical complexity, a prototype-dominated landscape, and institutional barriers to implementation.

Finally, advancing co-creative urban planning requires not only better tools, but also organisational change, including capacity building, facilitation expertise, and embedding participatory outputs into decision-making processes.

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Conflict of Interests

The authors declare no conflict of interests.

LLMs Disclosure

Claude was used for grammar and language polishing, with validity checked by the authors.

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